# Dynamometer Test Plan

## ECE 492 - Spring 2015


## Abstract

This document details the acceptance test plan for the dynamometer system being developed for the LFEV design project.



Revision 4.2.0
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# Summary

The dynamometer system being developed for the LFEV design project is intended to provide detailed characteristics of the Motor Controller System (MCS) over the entirety of it's operating range. These goals have been divided into 3 tiers:

### Tier 1: Project Essentials

These project goals absolutely must be completed to consider the project complete. Without any one of these goals, the project will not operate as intended:

- Dynamometer Operation - The motor will spin and torque data will be gathered.
- Torque Curve Generation - The torque data will be sufficient to generate a curve.
- Motor Controller Operation - It will be possible to adjust the motor velocity.
- Emergency Stop - There will be a stop button that cuts power to the device.
- Gear Ratio Selection - A gear ratio must be selected based on the dynamometer data.
- Sensor Spec. Sheet - The accuracy of onboard sensors will be determined.

### Tier 2: Project Features

These project goals are not essential for the operation of the device, but will probably need to be implemented in the future for the LFEV project to operate according to the FEV rules:

- Power Interface - The system will be capable of running on power from the TSI.
- VSCADA Interface - Data gathered will be accessible to VSCADA
- Hardware Uniformity - Hardware will abide by the rules laid out in GPR005 and the CDR.

### Tier 3: Nonessential Items

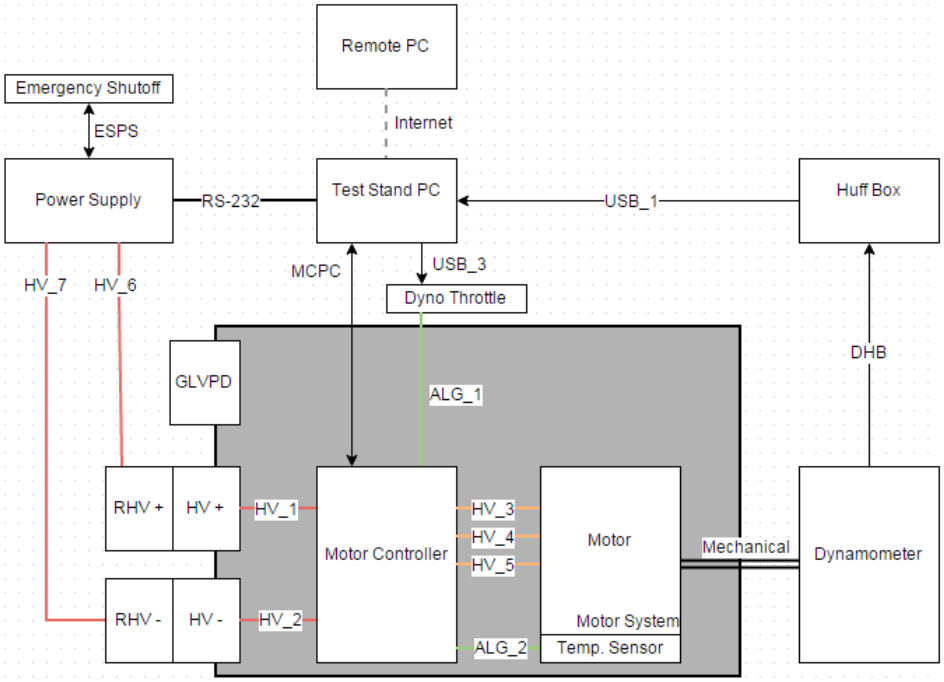
These project goals are merely interesting additions the device. They will probably never need to be implemented, but doing so may ease the design process for some aspect of the project:

- Mobile Test System - The motor testing and debugging hardware will be mobile.
- Automated Tests - All tests can be run without user input.

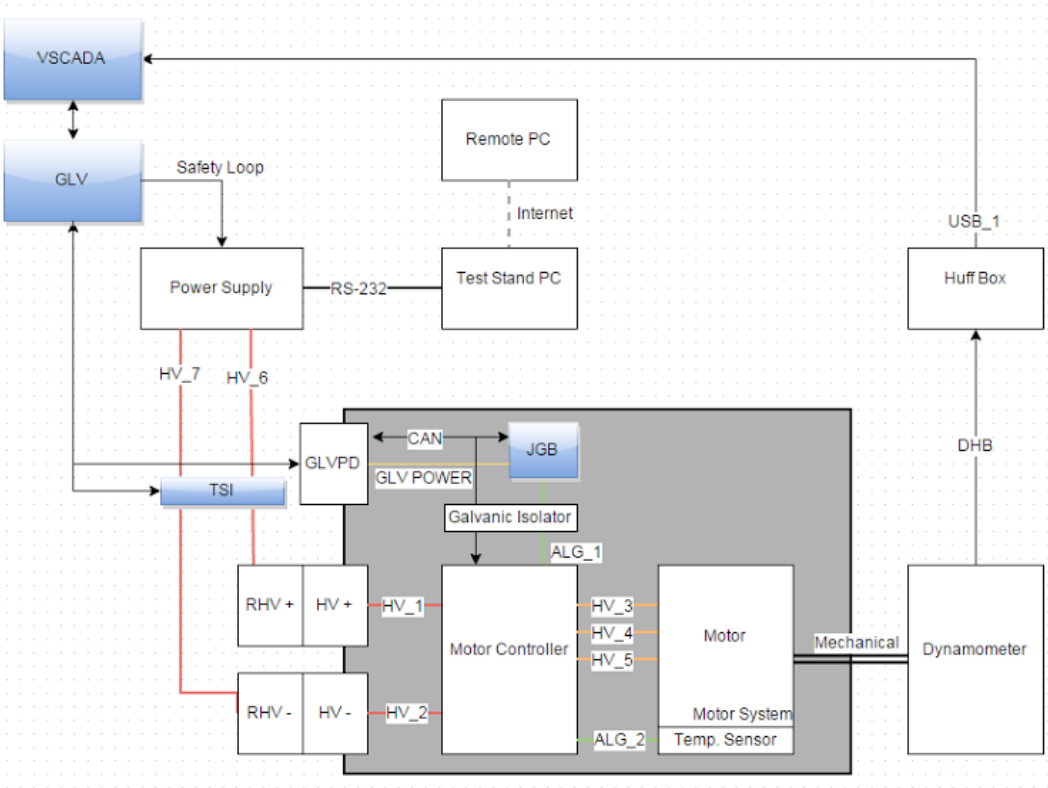
These items in these tiers are general suggestions for the priority of the tests listed in this document. For details on how tests will be performed on tier 1 and tier 2 goals, refer to the section on the related hardware. Tier 3 goals are not listed in this document.

Tests will be performed in various configurations, as specified for each test. These configurations are listed below:

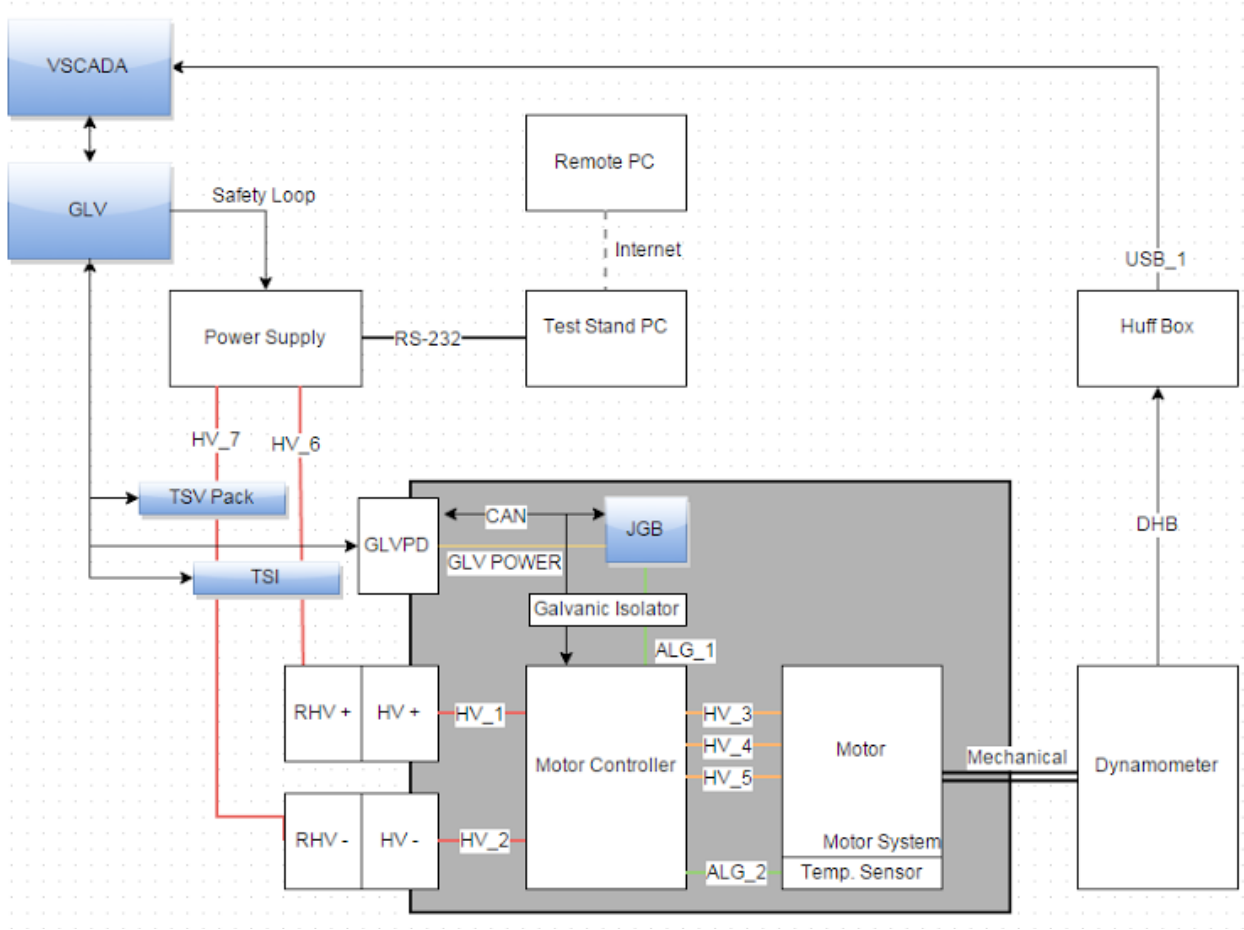
# Testing Configurations




**Configuration A:** Only Dyno systems




**Configuration B:** Includes VSCADA system for throttle control and data acquisition




**Configuration C:** Includes VSCADA and TSI

# Compliance Table

| Section | Systems | Functional Requirement/Interface |
|---|---|---|
| **R000** | **Formula Hybrid Competition Rules** | |
| **EV1.2.1** | Motor | The maximum permitted operating voltage for Formula Hybrid is 300 V. The maximum operating voltage is defined as the maximum measured accumulator voltage during normal charging conditions.<br><br>Note 1: The Tractive System Voltage limit may be exceeded within the motor/controller system as a result of transient inductive effects, but may not be intentionally increased through the use of DC/DC converters, transformers, etc.<br><br>Note 2: Commercially available motor controllers containing boost converters that have internal voltages greater than 300 VDC may be used provided the unit is approved in advance by the electrical rules committee. |
| | ACCEPTED - There is no way to generate 300V with the proposed system. | |
| **EV1.2.6** | Motor Controller | The tractive system motor(s) must be connected to the accumulator through a motor controller. Bypassing the control system and connecting the tractive system accumulator directly to the motor(s) is prohibited. |
| | ACCEPTED - The motor is only driven by the motor controller. | |
| **EV1.2.7** | Safety Loop | The GLV system must be powered up before it is possible to activate the tractive system. Furthermore, a failure causing the GLV system to shut down must immediately deactivate the tractive system as well. |
| | TEST - This is tested in T002-4. | |
| **EV2.1.2** | Sensors | The foot pedal must return to its original, rearward position when released. The foot pedal must have positive stops at both ends of its travel, preventing its sensors from being damaged or overstressed. |
| | N/A - The physical design of the throttle must be done in the vehicle itself. | |
| **EV2.2.1** | Safety Loop | All analog acceleration control signals (between accelerator pedal |

| | | |
|---|---|---|
| | | and motor controller) must have error checking which can detect open circuit, short to ground and short to sensor power and will shut down the torque production in less than one (1) second if a fault is detected. |
| | N/A - The throttle pedal is being monitored by the VSCADA system | |
| **EV4.5.1** | Cabling | All parts, especially live wires, contacts, etc. of the tractive system need to be isolated by non-conductive material or covers to be protected from being touched. In order to achieve this, it must not be possible to touch any tractive system connections with a 10 cm long, 0.6 cm diameter insulated test probe when the tractive system enclosures are in place. |
| | INSPECT - All components must be covered, and tractive system components must be properly sealed. | |
| **EV4.5.2** | Cabling | Non-conductive covers must prevent inadvertent human contact with any tractive system circuit. EV4.5.2 This must include crew members working on or inside the vehicle. Covers must be secure and adequately rigid. Body panels that must be removed to access other components, etc. are not a substitute for enclosing tractive system connections. |
| | INSPECT - All HV systems should be covered to prevent inadvertent contact. | |
| **EV4.5.6** | Cabling | All wires and terminals and other conductors used in the tractive system must be sized appropriately for the continuous rating of the fuse which protects them. Wires must be marked with wire gauge, temperature rating and insulation voltage rating. Alternatively a manufacturers part number printed on the wire is sufficient if this can be referenced to a manufacturers data sheet.<br><br>The minimum acceptable temperature rating for TSV cables is 90°C.<br><br>Note: Many high current fuses can allow significant overcurrent conditions which may be adequate to cover the peak power requirements and allow resizing of fusing and wiring according to continuous or RMS needs. |
| | ANALYSIS - verify that all cables are of the appropriate gauge. | |
| **EV4.5.7** | Cabling | All tractive system wiring must be done to professional standards with appropriately sized conductors and terminals and with adequate strain relief and protection from loosening due to vibration etc. Conductors and terminals cannot be modified from their original size/shape and must be appropriate for the |

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|---|---|---|
| | | connection being made. |
| | | INSPECT - All cables must be securely mounted. |
| EV4.6.1 | Safety | Every housing or enclosure containing parts of the tractive system except motor housings must be labeled with sticker(s) (minimum 4 x 4 cm) with a red or black lightning bolt on yellow background or red lightning bolt on white background. The sticker must also contain the text “High Voltage” or something similar if the voltage is more than 30 VDC or 25 VAC. |
| | | INSPECT - All housings of HV components must have HV stickers. |

| R002 | VSCADA | |
|---|---|---|
| R002-0 | Sensors | Must interface sensors so that VSCADA can monitor the following sensors;<br>● Tractive System DC current and motor phase currents<br>● Temperature of the motor system<br>● Data available from the motor controller<br>● Data available from the Dyno Test Stand, including torque and RPM |
| | | TEST - Testing and calibration for data accuracy is in T001. |
| R002-1 | Sensors | The LFEV system shall use a commercial motor controller with a computer interface already installed. VSCADA shall use this interface to access, record, and display all available motor controller data in a form that is integrated with the overall LFEV data display. |
| | | ACCEPT - The CANbus interface is integrated into the motor controller. |
| R002-2 | Sensors/ Dynamometer | The LFEV system shall use a commercial dynamometer with a data acquisition sensor hardware already installed. VSCADA shall use the data acquisition hardware interface to access, record, and display all available dynamometer data in a form that is integrated with the overall LFEV data display. |
| | | TEST - The VSCADA-Dyno communication is in test T002-1 and T002-2. |
| R002-3 | Motor Controller | VSCADA shall be capable of closed loop control and “scripting” of Motor Controller System (MCS) Test Stand operation. Specifically, it shall be possible to set motor RPM and torque through closed loop control as a function of time. |
| | | TEST - The VSCADA-Throttle control will be tested in T002-3. |

| R005 | Motor Controller, and Dynamometer Test Stand |
|---|---|

| | | |
|---|---|---|
| **R005-0** | All | A motor, controller, and dynamometer shall be assembled together along with all necessary mechanical parts, couplings, plumbing, fasteners, TSV and GLV cabling, cooling equipment, sensors, interlocks, safety shields, and cable dress per GPR005, and any other necessary item to create an integrated Motor Controller System (MCS) Test Stand. |
| | INSPECT - See that all of the things are integrated. | |
| **R005-1** | All | The MCS Test Stand shall permit the safe testing and demonstration of motor and controller performance over the operational parameters (RPM and torque profiles, both forward and reverse) implied by the IEEE Formula EV competition. |
| | TEST - Operation will be tested in various T001 tests.<br>ANALYSIS - RPM and torque profiles must be identified.<br>**NOTE:** Reverse will not be tested | |
| **R005-2** | Motor | The Motor to be used is the HPEVS AC 50. |
| | ACCEPTED - This is the motor that was purchased. | |
| **R005-3** | Controller | The Controller to be used is the Curtis 1238R – 7601. |
| | ACCEPTED - This is the motor controller that was purchased. | |
| **R005-4** | Dynamometer | The dynamometer to be used is the Huff HTH-150. |
| | ACCEPTED - This is the dynamometer that was purchased. | |
| **R005-5** | Sensors | The MCS Test Stand shall incorporate all necessary sensors and other interfaces necessary for the measurement and data acquisition (DAQ) of all relevant MCS operating parameters, including torque, RPM, motor phase voltage and current, controller input voltage and current, and system temperature at critical locations. |
| | TEST - Testing the involved sensor systems is T001.<br>**NOTE:** controller input must be measured by the TSV, and phase voltage will not be measured | |
| **R005-6** | Interface | The MCS Test Stand shall be interfaced to the VSCADA system, GLV Power, TSV Load Controller, Safety Loop Controller, as required to permit full operation of these auxiliary systems. |
| | TEST - The interface tests are in T002. GLV Power and the Safety Loop Controller do not need to be connected to the dynamometer for full operation. | |
| **R005-7** | Power Supply | TSV power shall be provided either by the TSV Accumulator battery packs, or by a commercial power supply. A Magna-Power TS Series IV power supply is available for use with this project and is suitable as a source of |

| | | |
|---|---|---|
| | | TSV power. |
| | TEST - T001-2 tests whether the system works on the Magna-Power power supply, and T002-4 tests whether the system works on TSV power. | |
| R005-8 | Power Supply Switch | It must be possible to switch between the power supply and battery packs as the source of TSV power without exposure to uninsulated TSV conductors or terminals. |
| | INSPECT - Power supply must be switchable without exposure to terminals. | |
| R005-9 | Dyno Safety Loop | The MCS Test Stand shall be interfaced to an independent safety loop system that meets formula EV safety requirements to force safe system shutdown should an unsafe condition occur including ground fault, overtemp, overspin, over torque, or operator actuation of prominently mounted Emergency Stop switches. |
| | TEST - E-Stop will be tested in T000-1.<br>TEST - Initial ground fault testing is in T000-2.<br>**NOTE:** The motor controller handles these conditions, other than the E-Stop and ground fault. Ground fault is handled in the TSI | |
| R005-10 | Dyno Safety | Safety plan must be created and approved by course instructions and the Director of Engineering before work can be done on the system |
| | DELIVERABLE - The safety plan will be developed and approved. | |

| R007 | Safety Loop | |
|---|---|---|
| R007-0 | Cabling | The cabling requirements for car installation shall be analyzed and a set of safety cables suitable for use on the car shall be designed, fabricated, and tested. In addition, cables required to support the MCS Test Stand shall be designed, fabricated, and tested. |
| | ANALYSIS - The test stand safety loop (the E-Stop) must have proper cables. | |

| R008 | TSV Load Controller | |
|---|---|---|
| R008-0 | Cabling | The cabling requirements for load controller shall be designed, fabricated, and tested to be required to support the MCS Test Stand |
| | TEST - This is tested in T002-4. | |

# T000: Safety

The MCS will have a safety system in place to minimize the risk of injury while operating the device. Beyond the safety plan developed in D001 - CDR, there must be an emergency stop button clearly located, and the physical design must adhere to several safety standards.

## T000-1: Emergency Stop (A)

The system will shut down when the emergency stop button is pressed. This button must be hardwired into the system to minimize the possibility of failure.

### Testing Procedure

The emergency stop button will be tested by operating the motor under normal conditions, then pressing the emergency stop button.

### Acceptance Threshold

The emergency stop button will be considered operational if the motor shuts down without any mechanical or electrical damage when the emergency stop button is pressed.

## T000-2: Ground Fault (C)

It must be ensured that all high voltage lines are galvanically isolated from all grounded systems. Thus, it must be done while integrated with the VSCADA and TSI systems, to act as the grounded systems. The dynamometer computer will not be galvanically isolated from the motor controller in configuration A.

### Testing Procedure

An ohmmeter will measure the resistance between ground and all wires that are not obviously isolated (i.e. the dynamometer sensors).

### Acceptance Threshold

A test point will be considered isolated if the resistance between it and ground is greater than one million ohms.

## T000-3: Oil Temperature (A)

The threshold for the oil temperature is required to be at least below 55℃ for burn safety reasons. The threshold for second degree burns at 55℃ is 17 seconds, which should be more than sufficient to prevent any serious injury.

### Testing Procedure

The safety system will be tripped while the power supply is on (but not connected to the motor controller) by using an external heat source. The temperature of the shutoff will be recorded using a handheld IR thermometer.

### Acceptance Threshold

The sensor will be tested at least 10 times and the distribution will be determined statistically (assuming normality). The system will be considered accepted if the data indicates with greater than 90% confidence that the power supply will be shut down before the temperature reaches 55℃.

# T001: Sensors

The sensors incorporated into the dynamometer test stand will be logged onto a connected PC. Verification of the following parameters will be based on data recorded by this PC or found by operators, and will be included in the final testing documentation.

## T001-1: Torque (A)

The accuracy of the torque sensor included with the huff dynamometer will be determined by testing the properties of the strain gauge itself against known physical quantities.

### Testing Procedure

A reading from the torque sensor will be taken when a weight is hung from the calibration point on the dynamometer to correlate the sensor values to mathematically derived torque values. Sensor values will then be gathered with the application of other weights at the calibration point.

### Acceptance Threshold

At minimum, the torque must be measured with at least 3 different weights, with 6 data points taken for each weight. This test will be considered accepted if the data gathered is sufficient to develop an estimated accuracy for the torque sensor.

## T001-2: Motor Velocity (A)

The motor velocity will be measured with various devices across all applicable ranges and will be shown to correlate to the throttle input device for all valid ranges. This must be verified for both the Curtis motor controller sensor and the Huff dynamometer

### Testing Procedure

The motor speed will be measured by sweeping the throttle between the values of 0 and 6500 RPM in increments of roughly 500, and measuring the velocity at each point with the motor controller sensor, the dynamometer sensor, and a handheld tachometer. The motor velocity must be held at a given test point for enough time to gain an accurate reading on each of these devices.

### Acceptance Threshold

This test will be considered accepted if the data gathered is sufficient to develop an estimated accuracy for the velocity sensor.

## T001-3: Motor Current (A)

The motor phase current will be measured using an external current sensor to find the current through on the the motor leads. This system will only be in place to verify the motor controller current value. All current measurements will otherwise use the motor controller estimate, given it is verified by this test.

### Testing Procedure

To test the motor current sensor, the motor controller will be operated at several points in its operating range, at minimum including a low, medium, and high torque and speed. The motor current shall be measured using the motor controller's onboard sensor and an external current sensor attached to a motor power lead. The data from the motor controller will be recorded in the external computer using the software tools included for the hardware, and the external current sensor value will be recorded by a technician in a safe area for the duration of the test.

### Acceptance Threshold

This test will be considered accepted if the data gathered is sufficient to develop an estimated accuracy for the Curtis current sensor.

## T001-4: Controller Input Voltage (A)

The voltage to the input of the controller will be monitored during operation. If at any point the voltage reaches unsafe levels the safety loop will be activated and cut the power to the system.

### Testing Procedure

To test the voltage sensor, the motor controller will be operated at several points in its operating range, at minimum including a low, medium, and high torque and speed. The input voltage shall be measured using the motor controller's onboard sensor and the attached power supply readout. The data from the motor controller and power supply will be recorded by the external computer using the software tools included for the hardware.

### Acceptance Threshold

This test will be considered accepted if the data gathered is sufficient to develop an estimated accuracy for the Curtis input voltage sensor.

## T001-5: Load Variance (A)

The load of the dynamometer must be configurable. This will be done through the included Huff software package.

### Testing Procedure

While the motor is spinning at 1000 RPM, the dynamometer valve will be actuated by the Huff software to create a low, medium, and heavy load on the motor.

### Acceptance Threshold

The load variance of the dynamometer will be considered operational if the torque reading changes with the varying load, in a manner that can be reasonably repeated.

# T002: Interfaces

Interfaces with various systems must be designed for the dynamometer test stand and MCS. These interfaces will be developed in conjunction with the teams in the Interface Control Document, and will be included in the final acceptance test documentation given that the respective system has also been completed.

## T002-1: VSCADA - Motor Controller (B)

The VSCADA system must be capable of recording sensor information from the motor controller. This will be done through the CANbus port provided in the motor controller.

### Testing Procedure

The motor controller will be powered up while connected to the VSCADA system, but the motor will not be operated.

### Acceptance Threshold

The interface between the VSCADA system and the motor controller will be considered operational if the VSCADA computer can retrieve the relevant metrics required by R002-0.

## T002-2: VSCADA - Dynamometer (B)

The VSCADA system must be capable of recording information from the Huff dynamometer. This will be done using the serial protocol established for the Huff data acquisition hardware.

### Testing Procedure

The motor test stand will be powered up while connected to the VSCADA system, but the motor will not be operated.

### Acceptance Threshold

The VSCADA-dynamometer interface will be considered operational if the VSCADA computer can retrieve the relevant metrics required by R002-0.

## T002-3: VSCADA - Throttle (B)

The VSCADA system must be capable of adjusting the throttle input on the motor controller. This will be done using an external CANbus receiver with an analog output connected to the motor controller throttle input.

### Testing Procedure

The motor speed will be measured by sweeping the throttle between the values of 0 and 4000 RPM in increments of 100. The velocity will be measured by both the VSCADA system and the Huff dynamometer at each data point.

### Acceptance Threshold

This test will be considered accepted if the data gathered is sufficient to develop an estimated accuracy for the VSCADA throttle control.

## T002-4: TSI - Motor Controller (C)

The system must shut down in the event of a ground fault, or if the safety loop is triggered by GLV.

### Testing Procedure

The power supply will be turned on, but the motor will not be operated for this test. The system must be shown to shut down in the event of a ground fault on any of the isolated lines.

### Acceptance Threshold

The TSI to motor controller interface will be considered complete if the system operates normally while the TSI is attached.

# Inspections

| | | | |
|---|---|---|---|
| **Interfaces** | **EV 1.2.1** | The motor may only connect to the motor controller | ☐ |
| | **R002-1** | VSCADA must communicate directly with the controller | ☐ |
| | **R005-8** | Power supply must be switchable without exposure to uninsulated cables. | ☐ |

| | | | |
|---|---|---|---|
| **Physical Design** | **EV4.5.1** | No tractive system terminals may be contacted by a 10 cm long, 0.6cm diameter test probe | ☐ |
| | **EV 4.5.2** | HV systems must be covered to prevent contact | ☐ |
| | **EV 4.5.7** | All cables must be securely mounted | ☐ |
| | **EV 4.6.1** | All HV enclosures must have HV stickers | ☐ |
| | **R005-0** | The MCS test stand must conform to GPR005 | ☐ |
| | **R007-0** | The E-Stop must have the proper cables | ☐ |

**Examiner Signature** **Date**

# Deliverables

These are deliverables will be verified analytically.

## Torque Curve

Examiner Signature _____ Date _____

## Sensor Spec. Sheet

Examiner Signature _____ Date _____

## Gear Ratio

Examiner Signature _____ Date _____

## Simulation

Examiner Signature _____ Date _____

## Safety Plan

Examiner Signature _____ Date _____

## PDR Presentation

Examiner Signature _____ Date _____

## CDR Presentation

Examiner Signature _____ Date _____

## User Manual

Examiner Signature _____ Date _____

## Final Report

Examiner Signature _____ Date _____

## Maintenance Manual

Examiner Signature _____ Date _____

## Acceptance Test Plan

Examiner Signature _____ Date _____

## QA Audit Report

Examiner Signature _____ Date _____

## Calibration and Accuracy

Examiner Signature _____ Date _____

## Project Poster

Examiner Signature

Date

## Inspection Report

Examiner Signature

Date

Examiner Signature

Date

Examiner Signature

Date

Examiner Signature

Date

Examiner Signature

Date

# Testing Results:

## Safety

**T000-1** Emergency Stop works ☐

**T000-2** Ground fault isolation ☐

| Point | Resistance | Pass ? |
|---|---|---|
| | Ω | ☐ |
| | Ω | ☐ |
| | Ω | ☐ |
| | Ω | ☐ |
| | Ω | ☐ |
| | Ω | ☐ |

**T000-3** Oil Temperature Shutoff ☐

| | | |
|---|---|---|
| ℃ | ℃ | ℃ |
| ℃ | ℃ | ℃ |
| ℃ | ℃ | ℃ |
| | | |
| Median: | Std. Dev: | Conf: |

**Examiner Signature**

Sensors

**T001-1** Torque Sensor ☐

| **Weight:** | | |
|---|---|---|
| Nm | Nm | Nm |
| Nm | Nm | Nm |
| Median: | Std. Dev: | Conf: |
| **Weight:** | | |
| Nm | Nm | Nm |
| Nm | Nm | Nm |
| Median: | Std. Dev: | Conf: |
| **Weight:** | | |
| Nm | Nm | Nm |
| Nm | Nm | Nm |
| Median: | Std. Dev: | Conf: |

**T001-2** Motor Velocity ☐

| Curtis | Huff | Tachometer | Curtis Diff | Huff Diff |
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| | | | | |
| Curtis: | Median: | Std. Dev: | Conf: | |
| Huff: | Median: | Std. Dev: | Conf: | |

**T001-3** Motor RMS Current ☐

| | Speed | Curtis | Multimeter | Diff |
|---|---|---|---|---|
| | | | | |
| **Low Torque** | | | | |
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| **Medium Torque** | | | | |
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| **High Torque** | | | | |
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| | | | | |
| | | Median: | Std. Dev: | Conf: |

**T001-4** Controller Input Voltage ☐

| | Speed | Curtis | Power Supply | Diff |
|---|---|---|---|---|
| | | | | |
| **Low Torque** | | | | |
| | | | | |
| | | | | |
| | | | | |
| **Medium Torque** | | | | |
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| | | | | |
| **High Torque** | | | | |
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| | | | | |
| | | | | |
| | | Median: | Std. Dev: | Conf: |

**T001-5** Load Variance ☐

| Load | Torque | Velocity |
|---|---|---|
| | | |
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| | | |
| | | |

**Examiner Signature**

Interfaces

**T002-1** VSCADA receives data ☐

**T002-2** VSCADA receives data ☐

**T002-3** VSCADA controls throttle ☐

| Desired | Actual | Diff |
|---|---|---|
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| | | |
| | | |
| | | |
| Median: | Std. Dev: | Conf: |

**T002-4** System works with TSI ☐

**Examiner Signature**